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On the vulnerability of Small Island Developing States: A dynamic analysis

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ABSTRACT

Small Island Developing States (SIDS) are generally considered highly vulnerable to climate change because they suffer from most common environmental problems due to their smallness, remoteness and exposure to natural hazards, though they contribute less to climate change. However, international cooperation can improve the negative impacts of climate change by incentivizing adaptation policies. The vulnerability assessment becomes crucial because it can be used to allocate the international cooperation resources targeted to adaptation plans.

The aim of this paper is to assess of the vulnerability in Small Island Developing States.

Using a comprehensive dataset including 32 variables, we synthetize the vulnerability with a composite indicator. Then, we analyze the vulnerability's dynamics over time from 2009 to 2014. Lastly, we explore the dimensions of vulnerability to assess those that have a greater weight on overall vulnerability. Our findings show that the vulnerability of Small Island Developing States is partly driven by common characteristics, such as isolation and extreme exposure to the effects of climate change, but the degree of vulnerability of identified dimensions is different among countries. Our results give indications to better target development aid, giving suggestions on the more relevant dimensions for action to reduce the vulnerability of each country.

1. Introduction

Small Island Developing States (SIDS) were first recognized as a distinct group at the United Nations Conference on Environment and Development in June 1992 where it was stated: "*Small Island Developing States, and islands supporting small communities are a special case both for environment and development. They are ecologically fragile and vulnerable. Their small size, limited resources, geographic dispersion and isolation from markets, place them at a disadvantage economically and prevent economies of scale*".[1] The United Nations – Department of Economic and Social Affairs (UN-DESA) currently recognizes 57 SIDS (37 UN-Members and 20 Non-UN), which are categorized into three main geographic areas: i) Caribbean, ii) Pacific and iii) Atlantic, Indian Ocean, Mediterranean and South China Sea (AIMS).

These countries suffer from the most common environmental problems (i.e., land degradation and biodiversity losses) due to their smallness, remoteness from the mainland and world markets, and high exposure to natural disasters (see, e.g., Briguglio 1995); these problems are further facilitated by population growth and urbanization (e.g., Barnett, 2011; Connell, 2013). SIDS are generally considered highly vulnerable to climate change. Climate change amplifies the negative consequences on these lands as sea-level rises or precipitation patterns change (Nurse et al., 2014) thereby reducing agriculture and fisheries, for example. The negative issues affect food security and employment and income, both because they are the main economic sectors and because they affect tourism, which represents one of the main components of the economy in these countries (see, e.g., Barnett, 2011; Yamamoto and Esteban, 2014). Another important sector linked to tourism and international trade is transportation, which is crucial in most SIDS due to the isolated location (Pratt, 2015).

To contrast and reduce the impacts of climate change, the UNFCCC, in 1992, highlighted two fundamental strategies: *i)* the cuts in GHG emissions from large emitters and *ii)* engaging in policies of climate adaptation. To reach these goals, a general framework requires assessing and monitoring the vulnerability of SIDS.

Although the interest to quantify vulnerability in the literature is high, divergences exist about a universally accepted definition (Beroy-Eitner, 2016; Hinkel, 2011). Kasperson and Kasperson (2001) define vulnerability as "the degree to which an exposure unit is susceptible to harm due to exposure, to a perturbation or stress, in conjunction with its ability to cope, recover, or fundamentally adapt". Füssel (2010) argues, indeed, that vulnerability can be interpreted narrowly as a lack of socio-economic capacity and entitlements to cope with the adverse impacts of climate change. Pratt et al. (2004a), in the manual of

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Environmental Vulnerability Index (EVI), state "When we talk about vulnerability, we are automatically also talking about resilience because the two are opposite sides of a single coin". On the other hand, the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (2014) defines vulnerability as the propensity or predisposition to be adversely affected, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.[2] Some authors (see e.g., Guillaumont, 2015, 2016) include the concept of resilience in the assessment of vulnerability. Moreover, the concept of vulnerability and/or resilience can regard specific aspects (i.e., economic vulnerability, environmental resilience) and/or particular areas (i.e., pacific area, developing countries). Garschagen and Romero-Lankao (2015) focus their attention on urbanization-vulnerability, suggesting that urbanization may have blurred effects on overall vulnerability whereas Nguyen et al. (2016), analyzing eco-tourism destinations, assess that eco-environmental vulnerability is the result of the composite of more processes affected by hydrometeorology, society economics, land resources, and topography. When the vulnerability – related to the intrinsic sensitivity to exposure to exogenous or endogenous risks and the capacity to manage or adapt to them – is discussed with respect to SIDS, the concept is mainly linked to their remoteness from main markets, dependence on energy and food and their small size, including the large range of impacts from climate change (UNDESA, 2015; UN-ECLAC, 2011; Beroya-Eitner, 2016; Bates et al., 2014; Briguglio, 2014). Guillaumont (2010), analyzing the economic vulnerability index built by the United Nations – Committee for Development Policy (UN-CDP) (see the United Nations report, 1999) argues that vulnerability in SIDS countries consists of three components, including the size and frequency of the exogenous shocks, the exposure to them and the country's resilience. Moreover, the IPCC Fifth Assessment Report identifies the effects of climate change in SIDS in three main areas: coastal systems, terrestrial systems and human systems.

The identification of the determinants of human and natural systems' sensitivity to climate change become strategic for targeting and evaluating adaptation plans for SIDS countries. The resource allocations to developing countries should be guided by reasonable and clear goals related to sector-specific or hazard-specific criteria (Füssel, 2010). Recently, Betzold and Weiler (2017) assessed that countries that are more exposed to climate change effects received more adaptation aid, although global climate finance is still fragmented (Pickering et al., 2017).

It follows that vulnerability is a multidimensional concept linked to management and governance of social-ecological systems (Miller et al., 2010). As complex dynamic system, vulnerability can be affected by feedback mechanisms inherent in social-ecological relations. Moreover, the feedback loop may be delayed in time and/or covered by economic alterations. For these reasons, researchers need to define the concept and the purposes to focus on specific intervention areas to improve the efficiency and effectiveness of adaptation policies.

The aims of this research are threefold: *i)* evaluating the vulnerability in SIDS and synthetizing it with a composite indicator (CI); *ii)* analyzing its dynamics, and then, *iii)* exploring its identified dimensions to assess those that have a greater weight on the vulnerability index. The results of these analyses are useful to better address policy-makers' interventions to promote the adaptation measures with respect to climate change. To reach these goals, we first built a vulnerability index that includes 32 variables representing four main areas (social, economic, environmental and remoteness) during the time span from 2009 to 2014. The importance of adaptation becomes even more marked if we consider that the economic development of a country depends not only on the improved coordination of received aid but also on the way aid is organized and distributed. This aspect is relevant in developing countries where the lack of natural resources and a low level of social development make the problem of vulnerability a key issue. Thus, this paper proposes a temporal and geographic comprehensive indicator for vulnerability in SIDS. Moreover, in this paper we identify the factors (economic, socio-demographic, etc.) that can negatively or positively affect the SIDS' vulnerability.

The remainder of the paper includes a presentation of the frameworks and data employed (Section 2) and the conceptual and methodological review (Section 3), results analysis and discussion (Section 4) and the check of robustness of proposed indices (Section 5) and concluding remarks (Section 6).

2. Framework and data

2.1. Framework

Several methods to assess vulnerability have been proposed in recent decades in all fields related to natural hazards, poverty analysis and sustainable livelihoods. The vulnerability assessment is crucial when it can be used to address the policies and funds for specific needs and priorities (Pickering et al., 2015). The concept of vulnerability, which varies widely across communities, sectors and regions, is the starting point for its assessment. As a consequence, the frameworks proposed in the literature for the construction of vulnerability indices are various and fragmented. Moreover, a second relevant issue concerns the lack of data for SIDS.

For the sake of simplicity, we can divide the framework proposed into two classes: one class in which vulnerability embeds the concept of resiliency, and a second class in which vulnerability is a multidimensional phenomenon that includes aspects linked to intrinsic characteristics of analyzed systems.

In the first class, we include several indices proposed by various international organizations and researchers. SOPAC (Pratt et al., 2004b) proposes a vulnerability index that assess the SIDS' vulnerability. This index synthetizes three aspects of vulnerability: *i)* risks to the environment, *ii)* the intrinsic ability of the environment to cope with the risks (resilience) and *iii)* ecosystem integrity. Bates et al. (2014), Bates and Angeon (2015), and Angeon and Bates (2015) propose a Vulnerability-Resilience index classifying the variables in five dimensions representing the economic, environmental, social, political/governance and peripheral dimensions. The UN-CDP (2015) proposes an economic vulnerability index that has two main components: an exposure index and a shock index. The indicator, assessing the size, location, economic structure, environment, trade and natural shocks of countries, includes some of the structural features of the latter that reflects resiliency. Guillamont (2016) proposes an index of structural vulnerability. The author considers, in a conceptual framework, some structural factors in the resilience of a country as the human assets index, the structural economic vulnerability and the state fragility as a sociopolitical dimension of vulnerability. Maiti et al. (2017), based on socio-economic and biophysical indicators, assess the social vulnerability in India's districts, considering the exposure, sensitivity and adaptive capacity as sub-sectors of vulnerability whereas Tapia et al. (2017) develop an indicator-based vulnerability assessment for European countries based on potential hazard-receptor combinations (impact chains) (i.e., heatwaves, drought and flooding).

Other indices can be included in the second class. Briguglio (2014) develops a framework to assess, separately, the economic vulnerability (inherent conditions that expose a system to harm) and economic resilience (associated with policy induced) for small states. The author identifies four components for economic vulnerability (trade openness, export concentration, dependence on strategic imports and proneness to natural disasters) and five components for economic resilience

[2] The IPCC, on the other hand, distinguishes vulnerability from resilience, defining the latter as the capacity inherent to social, economic, and environmental systems to cope with hazardous events, resuming a definition used in an Arctic Council report. For these reasons, the IPCC considers the adaptation in response to the impacts of climate change and the reduction of vulnerability as two important components of climate-resilient pathways.

(macroeconomic stability, market flexibility, political governance and institutions, social development and environmental management). Zaman and Vasile (2014) define the vulnerabilities as inherent features and the resilience as changes generated by implementing some policies; thus, the resilience refers to what may be done to mitigate the vulnerability of a country. The Fifth IPCC Assessment report (AR5) introduces a new approach to assess vulnerability,[3] focusing on climate change risks. The Risk-Based Framework for assessing adaptation opportunities, constraints, and limits employed by the IPCC draws on vulnerability and risk assessment, as well as climate adaptation. The measurement of vulnerability remains central to many adaptation metrics and initially it was approached by focusing primarily on the climate change impacts to which people and systems need to adapt (IPCC, 2014).

UN-DESA (2015) proposes the Vulnerability-Resilience Country Profile (VRCP) which represents a country-owned analytical framework for assessment of sustainable development in SIDS. VRCP identifies the contributing factors to SIDS vulnerabilities and groups them into four different classes: i) economic, social and environmental,[4] ii) small size, iii) remoteness from markets and iv) narrow resource base.

2.2. Data

To develop the vulnerability index, we use the VRCP as a reference framework, which includes the priorities highlighted in the SIDS Accelerated Modalities of Action (SAMOA) pathway. To reach our aims we created a SIDS' Vulnerability Index (VI) based on 32 exogenous variables clustered in four dimensions.

They are related to economic, social, environment, and remoteness factors. Definitions, data sources and descriptive statistics of variables for the full sample (33 countries) are shown in Table 1.

The VI has been replicated in the time span from 2009 to 2014. To make comparisons in the countries ranked, we adopt a benchmark. The lack of a vulnerability index in all regions prompted us to extend our index to 2005, representing our benchmark, when no financing aid had yet been provided. Although the world community has recognized the importance of vulnerability to climate change since 1992, the first climate funds were endorsed only in 2009 and disbursed in 2010 with the "Fast-start Finance". The "Fast-Start Finance" is a collective commitment approaching USD 30 billion for the period from 2010 to 2012 made by developed countries during the Conference of the Parties (COP15) to provide new and additional resources to developing countries to combat climate change.

The class of economic factors is useful to define SIDS' economic vulnerability, as suggested by Briguglio (1995, 2014) and UN-DESA (2015), considered their limited ability to diversify production, the strong dependence on a narrow range of exports and high import content (due also to their insularity). In this class, we include the generation of electricity from fossil fuels, the import value index and the share of food imported with respect to merchandise imports to take into account the economic dependence on world markets. To account for the economic resources (the first of which is the tourism sector) we consider the number of arrivals of international inbound tourists. We also include in this class of factors the per capita electricity consumption, which can be considered as a proxy of technological and economic progress (Romano et al., 2016). Lastly, we include a set of variables related to degree of human development: the percentage of terrestrial and marine protected areas, life expectancy at birth, the number of births to adolescents and the percentage of the population with access to electricity. These variables can be considered as a proxy for "cultural progress", hypothesizing that the higher the cultural development, the greater the ability to cope with climate-related threats (Maiti et al., 2017; O'Neill et al., 2014; Lemos et al., 2016; Eakin et al., 2014).

The concept of remoteness is linked with the characteristics of SIDS, to their insularity and to susceptibility to natural disasters due to climate change. In this class of factors, we include the liner shipping connectivity index, the distance − in kilometers − from the capital to the nearest continent, and the number of internet users.

In the social dimension of vulnerability, we included the factors that could potentially impact climate change and that can be damaged from it. Many SIDS, in fact, lie in tropical zones and have high population densities. Therefore, the climate and the human settlements create favorable conditions for the transmission of diseases and are susceptible to extreme weather events. Thus, we consider the population density, the growth rate of the population, the total population, the percentage of the urban population, and the death and fertility rates. To account for the human health vulnerability, we include the percentage of the population using improved sanitation facilities, the percentage of the population and urban population using an improved drinking water source, and the incidence of tuberculosis.

The environmental dimension includes the factors that are related to natural hazards and climate change. Thus, we consider renewable electricity generation, the country's total area, the percentage of land areas where elevation is below 5 m and the percentage of the total population living there, and finally the percentage of forest area. We also include the CO2 emissions per capita. Although the SIDS have a very low level of GHG emissions, they have a special vulnerability to climate change as assessed by the UNFCCC that is based on the equity considerations and considers that these countries as both low-capacity and highly vulnerable (Kline et al., 2016). Finally, we include the percentage of arable land, the average precipitation and the fisheries production, given that both agriculture and fisheries resources are vital to SIDS economies and both can be affected by climate change.

To assess the reliability of indicators in explaining the single unidimensional class of factors we use the Cronbach's alpha, a widely recognized statistic for diagnosing composite indicator construction for internal consistency (OECD, 2008). The desired range for a good coefficient value is between 0.70 and 0.90. The alpha values show good internal consistency for two of four classes (the economic and social classes). The class of environmental factors has an alpha value of 0.62. The class that represents the remoteness shows a moderate level of internal consistency (Cronbach's alpha is 0.55). These moderate values suggest acceptable levels of internal reliability to build the composite indices on the world scale (Cutter et al., 2014; Tapia, 2017).

To summarize the information included in the variables considered we employ a composite indicator.

3. Method

The previous section reveals the multidimensional features of the dataset employed to construct the proposed indices. To reach our aim we construct a series of vulnerability indices over time (from 2009 to 2014 and fixing 2005 as the reference year) explaining their determinants.

A common methodology employed to make comparisons across space (and over time) is to combine various indicators in a single index. According to the OECD (2008), "A composite indicator (CI) is formed when individual indicators are compiled into a single index, on the basis of an underlying model of the multi-dimensional concept that is

[3] Previously, IPCC proposed other approaches to measure vulnerability: i) a "Vulnerability-based" approach that focuses on the risks themselves by concentrating on the propensity to be harmed, and ii) an "Adaptation-based" that examines the adaptive capacity and adaptation measures necessary to improve the resilience of a system exposed to climate change.

[4] Based on this framework, the economic vulnerability considers the risks faced by economies from exogenous shocks to the systems of production and distribution and from the very high exposure to economic conditions in the rest of the world. The social vulnerability is defined by UNDP as the degree to which societies or socio-economic groups are affected by stresses and hazards, whereas the environmental vulnerability refers to risks of loss and/or deterioration to a country's natural ecosystem, including any events that can cause damage.

Table 1
Definitions, data sources and descriptive statistics (in parentheses the Cronbach's α).

Class and (Cronbach's α)	Variable	Definition	Source	Mean	Std. Dev.	Min	Max
Social (0.82)	Population density	Population density is midyear population divided by land area in square kilometers.	World Bank	483.43	1,251.83	3.15	7,736.53
	Population growth	Annual population growth rate for year t is the exponential rate of growth of midyear population from year t-1 to t.	World Bank[a]	1.25	1.06	−2.63	7.05
	Population, total	Total population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship.	World Bank[a]	1,769,916	3,114,900	49,139	11,400,000
	Urban population	Urban population refers to people living in urban areas.	World Bank	45.79	22.46	8.55	100.00
	Urban population growth	Urban population growth rate refers to people living in urban areas as defined	World Bank	1.55	1.80	−3.26	7.07
	Death rate	Crude death rate indicates the number of deaths occurring during the year, per 1000 population.	World Bank[a]	6.96	1.90	2.30	14.09
	Fertility rate, total	Total fertility rate represents the number of children that would be born to a woman.	World Bank[a]	2.72	1.05	1.15	5.40
	Improved sanitation facilities	Access to improved sanitation facilities refers to the percentage of the population using improved sanitation facilities.	World Bank	75.22	26.31	15.60	100.00
	Improved water source (total)	Access to an improved water source refers to the percentage of the population using an improved drinking water source.	World Bank	90.64	13.38	37.10	100.00
	Improved water source (urban)	Access to an improved water source refers to the percentage of the population using an improved drinking water source.	World Bank	95.30	6.11	64.90	100.00
	Incidence of tuberculosis	Incidence of tuberculosis is the estimated number of new and relapse tuberculosis cases arising in a given year, expressed as the rate per 100,000 population.	World Bank	73.73	116.18	0.00	469.00
Environmental (0.62)	CO2 emissions	Metric tons per capita emissions are those stemming from the burning of fossil fuels and the manufacture of cement.	World Bank	4.59	7.13	0.15	36.07
	Renewables Electricity Generation	Total Renewable Electricity Production (Billion Kwh)	U.S. Energy Information Administration	0.24	0.44	0.00	2.07
	Surface area	Surface area is a country's total area, including areas under inland bodies of water and some coastal waterways.	World Bank	36,222.04	89,418.25	180.00	462,840.00
	Land area where elevation is below 5 m	Land area below 5 m is the percentage of total land where the elevation is 5 m or less. (sq. km)	World Bank	9.09	14.75	0.37	54.60
	Population living in areas where elevation is below 5 m	Population below 5 m is the percentage of the total population living in areas where the elevation is 5 m or less.	World Bank	10.36	13.69	0.49	56.20
	Forest area	Forest area is land under natural or planted stands of trees of at least 5 m in situ (sq. km)	World Bank	41.54	26.93	0.61	98.53
	Arable land	Arable land includes land defined by the FAO. (sq. km)	World Bank[c]	11.18	11.20	0.17	41.90
	Average precipitation in depth	Average precipitation is the long-term average in depth (over space and time) of annual precipitation in the country. (mm per year)	World Bank[b]	1,879.89	788.75	23.70	4,091.80
	Capture fisheries production	Capture fisheries production measures the volume of fish (metric tons).	World Bank	38,548.23	60,224.45	138.00	399,928.00
Remoteness (0.56)	Internet users (per 100 people)	Internet users are individuals who have used the Internet (from any location) in the last 12 months.	World Bank	32.68	22.42	0.84	90.50
	Liner shipping connectivity index	The Liner Shipping Connectivity Index captures how well countries are connected to global shipping networks (maximum value in 2004 = 100).	World Bank	10.46	17.86	1.28	113.00
	Distance	Distance in kilometers from capital to nearest continent	UNEP-GRID (Dahl, 1991)	810.94	1,028.91	0.00	3,800.00
Economic (0.78)	Terrestrial and marine protected areas	Terrestrial protected areas are totally or partially protected areas of at least 1,000 ha that are designated by national authorities as scientific reserves	World Bank	2.86	4.39	0.00	18.60
	Life expectancy at birth, total	Life expectancy at birth indicates the number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life.	World Bank[a]	71.18	5.61	52.34	82.65
	Adolescent fertility rate	Adolescent fertility rate is the number of births per 1000 women ages 15–19.	World Bank	49.69	25.31	3.83	124.00
	Access to electricity	Access to electricity is the percentage of population with access to electricity.	World Bank	81.45	26.81	0.08	100.00
	Electricity Consumption	Total Electricity Consumption (Billion Kwh)	World Bank	3.53	8.42	0.01	45.05
	Import value index	Import value indexes are the current value of imports (c.i.f.) converted to U.S. dollars and expressed as a percentage of the average for the base period (2000).	World Bank	250.09	118.74	52.30	659.00
	Food imports	Food comprises the commodities in SITC: food and live animals, beverages and tobacco, animal and vegetable oils and fats, and oil seeds, oil nuts, and oil kernels	World Bank	24.71	19.70	2.83	143.00
	Electricity Consumption per capita	Total Primary Energy Consumption per Capita (MillionBtu per Person)	U.S. Energy Information Administration	3.42	8.26	0.00	45.50

(continued on next page)

Table 1 (*continued*)

Class and (Cronbach's α)	Variable	Definition	Source	Mean	Std. Dev.	Min	Max
	International tourism, number of arrivals	International inbound tourists (overnight visitors) are the number of tourists who travel to a country other than that in which they have their usual residence.	World Bank	1,096,649.00	2,323,593.00	3,900.00	12,000,000.00

[a] Imputation missing data from U.S. Census Bureau.
[b] Imputation missing data CRU TS v. 4.00 Climatic Research Unit Time series.
[c] Imputation missing data from FAO (FAOSTAT).

being measured".

A CI has the advantage of allowing the ranking of countries because it represents overall environmental performance (Burck et al., 2009) in one number. Two of the greatest difficulties are the selection of variables and indicators and the determination of the weights that should be assigned to them to differentiate their correlation with vulnerability.

To remove the scale effect, we normalized the raw data using the Min-Max method, which can be used in conjunction with all the weighting schemes and for all aggregation systems making directional adjustments in a normalization procedure.

Following the suggested framework, first basing on the correlation structure shown by the variables, we treat highly collinear indicators within a given sub-dimension, counting them as a single indicator by performing Principal Component Analysis (PCA) (Saisana, 2012). The sub-dimensions estimated are equal to the component score multiplied by their proportion of variance.

In the second step, to combine sub-dimensions into dimensions we combine them by equal weighted geometric aggregation because it entails partial (non-constant) compensability of indicators (OECD, 2008). Using the equal weight (EW) aggregation method, each sub-dimension is assigned the same weight, or:

$$w_q = 1/Q \tag{1}$$

where w_q is the weight for the q-th sub-dimension ($q = 1,..,Q$) for each country.

To obtain the dimension of the composite indicator, we aggregate the weights for each indicator using the geometric methods:

$$\mathrm{dim}_c = \prod_{q=1}^{Q} X_{q,c}^{w_q} \tag{2}$$

Finally, we aggregate the dimensions of phenomena in the Composite Indicator. Thus, in the last step, we aggregate the dimensions using the weighted geometric average (following Eq. (2)). The weighting procedure, according to the PCA, follows the OECD (2008): i) the number of latent factors was extracted according to the criteria proposed by OECD (2008). This is, i) the number of factors with eigenvalues larger than one; ii) the number of factors with individual contributions to overall variance by more than 10%, and iii) the number of factors with cumulative contributions to overall variance by more than 60%. Then, the varimax rotation was used to maximize the variance of loadings; ii) weights were defined based on the matrix of factor loadings after rotation. First, normalized square factor loadings are computed; subsequently, we group the sub-indicators with the highest factor loadings and aggregate them by weighting each composite using the proportion of the explained variance in the dataset.

4. Results and discussion

The aims of our research are threefold: *i*) assessing SIDS' vulnerability by using the Vulnerability Index (VI), *ii*) analyzing the temporal and geographic evolution of vulnerability and *iii*) uncovering the determinants of vulnerability of SIDS by exploring the dimensions of VI. The results can assist policy-makers in prioritizing certain sectors in terms of resource allocation or requesting development assistance. As argued by the UNFCCC (2005), financial resources available to SIDS to propose and adopt adaptation policies are limited, thus they need international assistance to cope with the adverse impacts of climate change and achieve sustainable development.

To assess the vulnerability, we develop a composite indicator (CI). The proposed CIs summarize the main four dimensions of vulnerability (social, economic, remoteness and environmental) both as impacts from climate change (i.e., land area where elevation is below five meters) and as factors that can stress the overall vulnerability (i.e., population density and tourism). It was replicated for years from 2009 to 2014 while the index for 2005 is considered a benchmark for the dynamic analysis. Thus, the Vulnerability Index (VI) has the advantage of

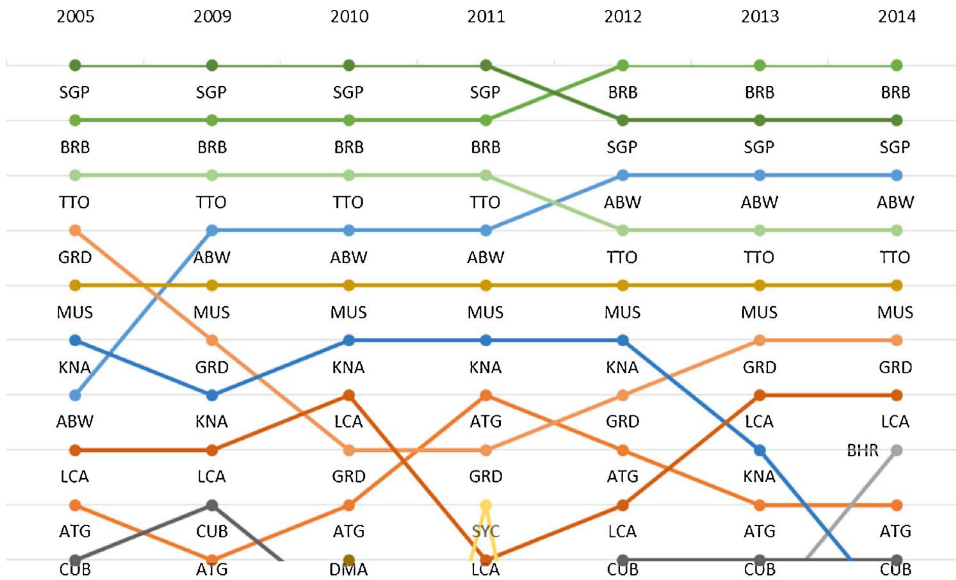

Fig. 1. Vulnerability index ranking for the least vulnerable countries (top ten). Year 2009–2014 (2005 as benchmark) – ISO code in Appendix.

allowing the ranking of countries over time.

The Vulnerability Indices (VIs) for each country over time are reported in Appendix A.

4.1. Dynamics of vulnerability

The VI is a number between 0 and 1. The least vulnerable countries are closer to 0 while higher values of the index indicate countries that are the most vulnerable.

Focusing on the VI in 2005 we observe that the values are between 0.09 (Singapore) and 0.59 (Kiribati) while in 2014 the values are between 0.13 (Barbados) and 0.62 (Kiribati) (see Appendix A).

For the whole time span considered, which is 2005–2014, Fig. 1 reports the ten least vulnerable countries while Fig. 2 reports the ten most vulnerable countries.

Among the most vulnerable countries, Kiribati is in last place preceded by Papua New Guinea, the Solomon Islands, and Vanuatu. All these countries are situated in the Pacific region and in particular in the *Ring-of-fire area*, where earthquakes and tsunamis are very frequent. Kiribati is in the Micronesia region and is the last in the Melanesian one. Countries are seriously threatened with flooding due to sea-level rises. Kiribati has been stable over time as the most vulnerable state. Haiti, instead, is in the Caribbean Sea and it is regularly hit by tropical storms and powerful earthquakes. In the time span considered, Haiti increased in vulnerability. That could be due to the hurricane season in 2008, when Haiti was battered by four storms, which killed more than 800 people and devastated nearly three-quarters of its agricultural land and to the earthquake in 2010. Both are an example of how natural disasters enhance the vulnerability of the countries. Vanuatu showed a decrease on the VI while Papa New Guinea showed a decrease between 2009 and 2011 before showing a subsequent increase. The VI of the Maldives decreased only in 2009 and otherwise increased in vulnerability. Kiribati, Haiti and Papa New Guinea are among the larger and least globally connected countries. They are also among the states that are the most severely affected by natural disasters.

Focusing on the least vulnerable countries, we observe that in the first part, until 2011, Singapore was the least vulnerable country, while since 2012 Barbados has occupied the first position in the ranking of countries.

These countries (Singapore and Barbados) remain stable in the top positions among countries that are the least vulnerable. Aruba shows a great improvement because it reduced its vulnerability. Mauritius remains stable while St. Kitts and Nevis increased in vulnerability since 2012.

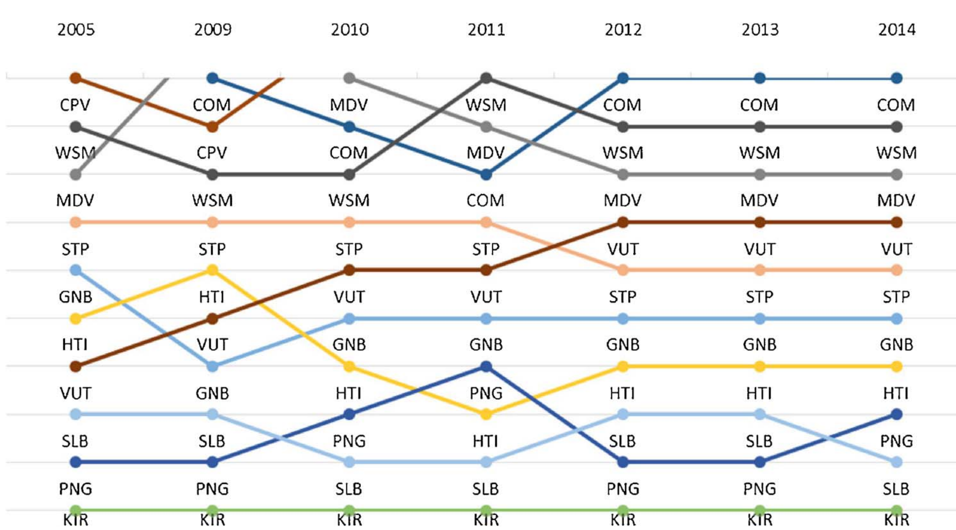

Fig. 2. Vulnerability index ranking for the most vulnerable countries (last ten). Year 2009–2014 (2005 as benchmark) – ISO code in Appendix.

4.2. Determinants of vulnerability

SIDS countries are generally the most vulnerable countries in the world, and this is in part driven by several common vulnerabilities such as isolation and by the extreme exposure to the effects of climate change. However, the degree of overall exposure changes with regard to analyzed dimensions of vulnerability. The analysis of dimensions of vulnerability can suggest designing policies targeted to specific sectors to cope with the adverse effects of climate change. Guillamont (2016) argues that the composite indices, summarizing all variability of phenomena, can give suggestions to identify and rank the countries but make it difficult to target policy interventions to reduce the vulnerability. Nevertheless, the designed vulnerability profiles for countries, having more qualitative information and relying on a small number of relevant and well-identified components, are suitable to promote and support adaptation processes to face the adverse climate change issues.

To better address the policies' actions, we analyze separately the four identified dimensions to find the more sensitive areas for each country.

To summarize the relevance of the remoteness, economic, environmental and social factors in VIs aggregation we employ a radar diagram. The weights are expressed by the factor loadings of the four dimensions and each axis represents the dimension. The ideal countries (not-vulnerable) reach the score 0 on any dimension, positioning themselves in the center of the diagram. The highest score, corresponding to the most vulnerable countries, is shown on the diagram's perimeter. Diagrams for the least and most vulnerable SIDS are presented in Fig. 3.[5]

Analyzing the dimensions of VIs, we observe that the patterns described by the diagrams, from 2005 to 2014, remain almost constant over time. The configurations described by the dimensions of VI's least vulnerable countries (Singapore, Barbados, Aruba, Trinidad and Tobago and Mauritius) are very close to the center of the plot. The most vulnerable countries, such as Kiribati, the Solomon Islands, Papa New Guinea, Haiti and Guinea-Bissau have high scores on all dimensions.

Kiribati, Papua New Guinea and the Solomon Islands are the most vulnerable small states. These countries show the highest values of vulnerability in three of the four dimensions. Kiribati shows a high vulnerability in social, environment and remoteness dimensions. The country, one of the most remote countries in the world, with its numerous atolls, has high transportation costs that limit production opportunities and underpin the high public sector expenditure (IMF, 2016). Moreover, it is most affected by climate change impacts in terms of lost lands due to sea-level increases and flooding, which affects population health in terms of extreme poverty and lack of sanitation. Another important issue is related to shoreline recession due to sea-level increases that led to destroying coastal villages and, consequently, to community relocation (Albert et al., 2016). The authors, analyzing the coastal dynamics of the Solomon Islands, argue that the vulnerability and fragility of the country is linked to the negative combined effects of wind energy and sea-level increases. Haiti, located in the Caribbean Sea, has high scores in the social and economic dimensions. Haiti is highly vulnerable to earthquakes, hurricanes and cyclones. The effects of the latter, greatly influenced and exacerbated by the country's poverty, include wind damage, flooding and coastal surges that affect the rural population health. Guinea-Bissau is located in Africa and, as with Haiti, shows high values in the social and economic dimensions. The lack of water and sanitation, due to extreme poverty, and the rainy season are the main cause of cholera. This, together with the lack of food security and the high rate of the rural population, represent the main factors of vulnerability that affect the country.

At the other extreme, there are Singapore and Barbados. Singapore, in the small states context, does not suffer from its remoteness, having greater interlinking and diversified markets (mostly with the USA and China). Moreover, the economic dimension that summarizes the different aspects of human development has an irrelevant weight on the vulnerability of the country. The country shows a moderate score only in the social dimension, due to high population density and to the high growth rate of urbanization. The latter is a driver of increased exposure in densely populated areas (increasing vulnerability to coastal change). Barbados and Trinidad and Tobago − both in the Caribbean Sea − instead, have similar profiles of vulnerability, showing, in 2005, comparable scores on only three relevant dimensions: economic, environment and remoteness. Mauritius, lastly, located in Indian Ocean, suffers mainly from high isolation.

SIDS countries generally have limited resources, thus they cannot undertake a path alone towards the sustainability of development and the implementation of adaptation policies.

Pelling and Uitto (2001) suggest that urbanization, foreign direct investment, and cultural modernization can contrast and reduce the vulnerability of SIDS. In addition, the UNDP and UN-OHRLLS (2015) discuss the important role of human development that influences the capacity of the country to attract foreign financial sources. Some countries, as Barbados and Singapore, show very high levels of human development while others, such as Guinea-Bissau and Haiti, score poorly. These countries also present different capacities to mobilize domestic resources and to attract external finance. Thus, countries at similar income levels face very different specific vulnerabilities that they need to account for to promote targeted interventions. Other criticisms are due to the infrastructure and service development, especially in the electricity generation systems. Some of the SIDS countries have very low electrification rates. Lucas et al. (2017) argued about the significant reduction in the cost of RE technologies that improved their reliability, making these technologies an attractive alternative for SIDS countries. Furthermore, they have potential for small hydropower stations, albeit financing to promote the extension of the grid rather than off-grid solutions that is more suitable given the specific geography of fragmented archipelagos (Betzold, 2016).

Almost all countries, among the most vulnerable countries, are classified as Least Developed Countries (LCD)[6] except three: the Maldives, Samoa (they graduated from the category in 2011 and 2014, respectively) and Papua New Guinea. Most of the SIDS countries (except for Aruba, Barbados, Singapore, Trinidad and Tobago, Saint Kitts and Nevis) are eligible to receive official development assistance[7] (ODA) even though they do not have the LCD status. The external financial resources can promote investments to help these countries to cope with the effects of environmental worsening and, thus, decrease their vulnerability. The international cooperation funds contrast the vulnerability promoting the adaptation policies to combat the effects of climate change in SIDS countries. Nevertheless, foreign direct investments can play an important role in supporting the diffusion of green technologies (Lohani et al., 2016).

Vulnerability is a very relevant topic mostly for SIDS countries that contribute less to climate change, but suffer the most from the consequences. However, the adoption of adaptation policies is costly and they need international co-operation to cope with the negative climate change's impacts. The results give indications to better target the development aids to promote adaptation strategies suggesting the more relevant dimensions on which countries need to act to reduce their vulnerability.

[5] To economize space and improve the readability of the graph we report the diagram of the five least and the five most vulnerable countries in 2005, 2010 and 2014. However, all other data are available from the authors by request.

[6] To be included in the list countries must have low incomes and face severe structural impediments to sustainable development. They are also extremely vulnerable to economic and environmental shocks and have low levels of human capital.

[7] The countries are included in the Organization for Economic Cooperation and Development – Development Assistance Committee (OECD-DAC) List of ODA Recipients, which is effective at 1 January 2015 for reporting on 2014, 2015 and 2016 flows.

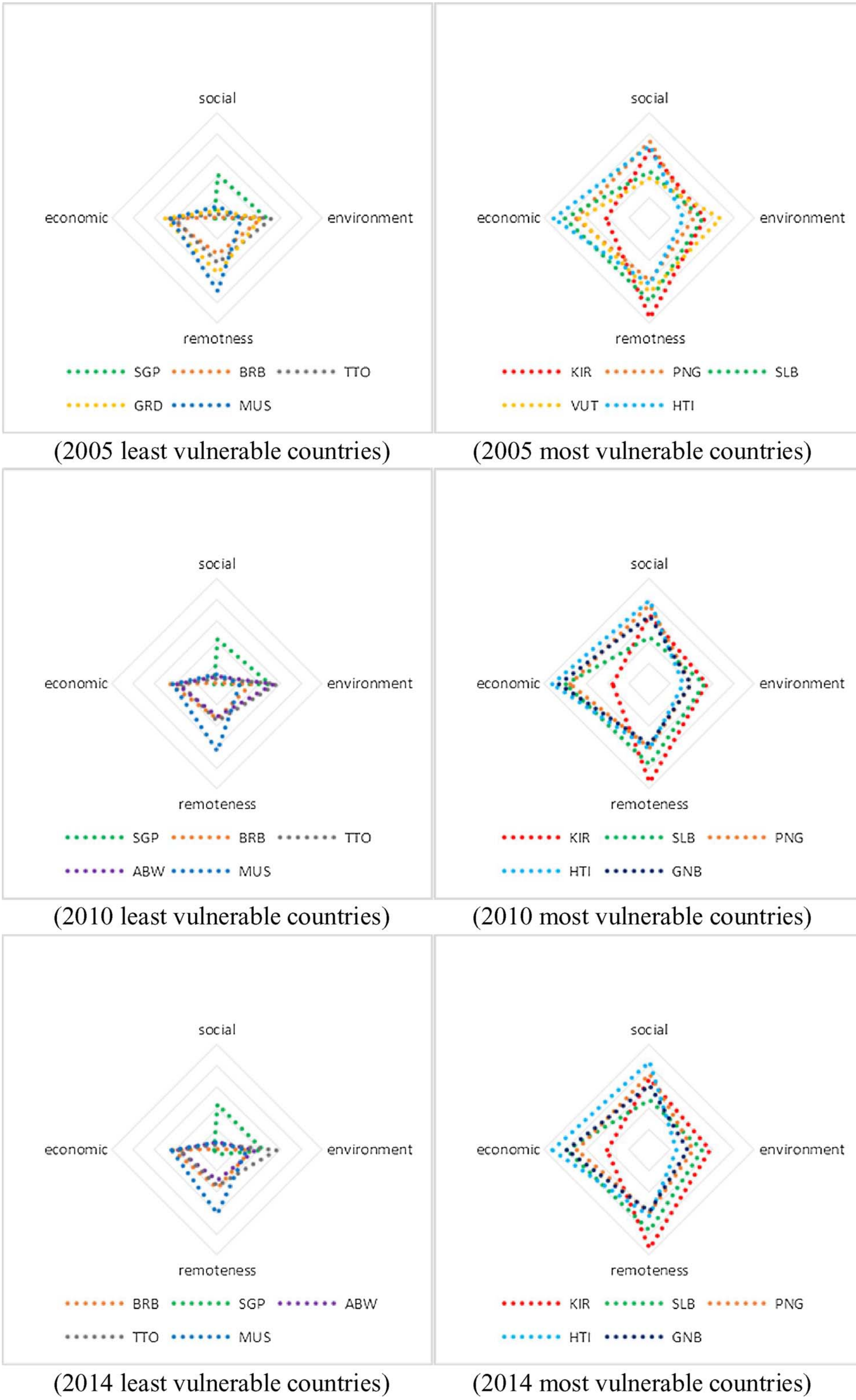

Fig. 3. Radar diagrams of the vulnerability index dimensions for the five least and most vulnerable countries in 2005, 2010 and 2014 (ISO code in Appendix).

5. Robustness checks

Although several indicators have been produced in all fields of research, those related to environmental issues have often been criticized (Hinkel, 2011). The main concerns are the lack of clear definitions of phenomena to assess and, thus, of a clear theoretical framework. Moreover, with regard to methodological aspects, there are many different types and sources of uncertainty descending from choice of subgroups and categories (and then of variables' selection) to weighting and normalization of sub-indicators, subgroups and categories (Burgass et al., 2017). This implies that the quality and reliability of a composite index needs to be evaluated to ensure the validity of the policy conclusions.

This section presents the main conclusions of the uncertainty analysis.

We propose the checking of the robustness of indices presented in

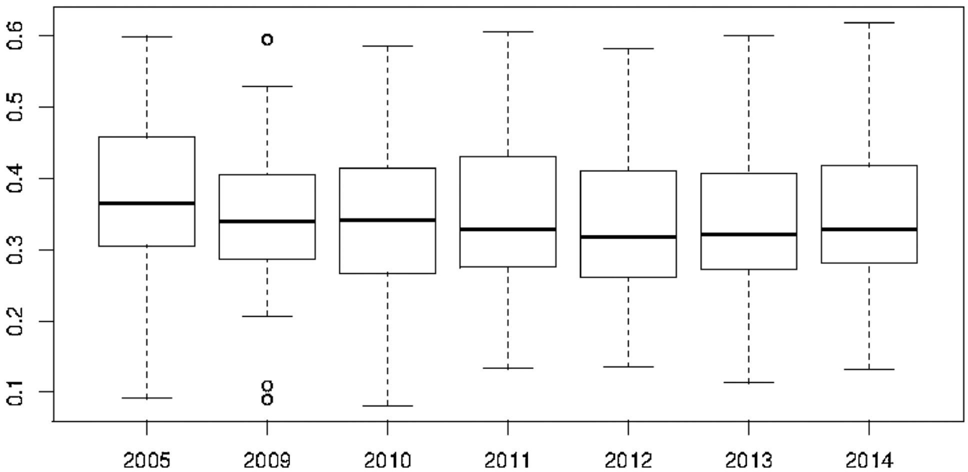

Fig. 4. Boxplot of annual VI's distribution.

two dimensions: i) stability over time and ii) reliability with respect to aggregation methods.

The annual distribution of the VI is reported in Fig. 4. The homogeneity of the proposed indices over time is reflected in the time box plots representing the indices' variation in the SIDS countries. The median values have a relatively low range of variation among the VI over time. In 2009, we observe the presence of some outliers in the index distribution. These can be due to the inflow of capital into developing countries turned into a trickle due to the downturn in the US and European markets putting pressure on exchange rates and causing unprecedented increases in the costs of credit.

The subjective judgments in calculation procedure of composite indicator, such as the selection of indicators, the choice of aggregation model and the weights, can led to uncertainties. To evaluate one of the main source of uncertainties associated with the methodology followed we check other procedures of aggregation and weights. After combining the simple indicators in sub-dimensions (to treat the high collinearity among variables of a same sub-dimension) by performing the PCA, in the following step, we aggregate the sub-dimensions in a single dimension using *i)* PCA (as done to obtain the sub-dimensions) and *ii)* equal weighted geometric average. Finally, we develop other two composite indicators by combining the dimensions with the equal weighted geometric aggregation method.

Summarizing, we obtain the following CIs:

- CIgg: the sub-dimensions were combined by EW geometric average; in the same way we combined the dimensions.
- CIpg: the sub-dimensions were combined in a single dimension equal to component score multiplied by its proportion variance; the dimensions are aggregated by EW geometric average.

Table 2 compares the ranking of the countries based on the three different aggregation methods that are employed. Overall, there are no significant changes in the ranking of the different countries between the three aggregation methods, which is evidence of the robustness of our results.

Table 2
Composite indicator for vulnerability country rankings by different aggregation methods.

Country	2005			2010			2014		
	VI	CIgg	CIpg	VI	CIgg	CIpg	VI	CIgg	CIpg
Aruba	7	7	3	4	4	2	3	3	1
Antigua and Barbuda	9	11	11	9	9	5	9	10	3
Bahrain	21	18	14	16	12	14	8	6	10
Bahamas, The	14	15	6	13	13	6	14	14	4
Belize	18	12	9	22	15	19	19	12	8
Barbados	2	2	1	2	2	1	1	2	2
Comoros	22	23	23	25	26	26	24	25	25
Cabo Verde	24	24	25	23	24	22	23	24	21
Cuba	10	8	10	11	10	9	10	8	12
Dominica	11	10	13	10	11	11	12	13	11
Dominican Republic	16	14	21	19	18	24	18	17	22
Fiji	23	22	24	21	22	21	21	21	24
Guinea-Bissau	28	28	32	29	30	31	29	29	29
Grenada	4	6	7	8	8	10	6	7	9
Guyana	19	21	22	17	19	23	17	20	20
Haiti	29	30	30	30	33	32	30	31	32
Jamaica	17	19	18	14	17	18	15	18	16
Kiribati	33	32	28	33	29	28	33	33	30
St. Kitts and Nevis	6	4	4	6	6	4	11	11	7
St. Lucia	8	9	15	7	7	13	7	9	13
Maldives	26	25	19	24	23	16	26	26	19
Mauritius	5	5	2	5	5	3	5	5	6
Papua New Guinea	32	31	33	31	31	33	31	30	33
Singapore	1	1	5	1	1	8	2	1	15
Solomon Islands	31	33	31	32	32	30	32	32	31
Sao Tome and Principe	27	27	26	27	27	27	28	28	28
Suriname	15	16	17	15	16	17	16	16	18
Seychelles	13	17	20	18	21	20	22	22	23
Tonga	20	20	12	20	20	12	20	19	14
Trinidad and Tobago	3	3	8	3	3	7	4	4	5
St. Vincent and the Grenadines	12	13	16	12	14	15	13	15	17
Vanuatu	30	29	29	28	28	29	27	27	27
Samoa	25	26	27	26	25	25	25	23	26

6. Conclusion

Small Island Developing States are generally considered highly vulnerable to climate change and suffer from a lack of natural resources, have a relatively small domestic market and are dependent on foreign markets and financing. Moreover, the contribution to global warming of SIDS is low in term of total carbon emissions, although they are the most likely to suffer the adverse effects of climate change (Kline et al., 2016). As argued by Briguglio (2014) and Becker (2012), their geographic isolation increases their economic vulnerability due to their strong dependence on narrow resources from the main world markets.

In this paper, we analyze the SIDS's vulnerability and its determinants over time. We propose a composite indicator to summarize and assess the multidimensional phenomena of the vulnerability of countries. To summarize the principal aspects that came to light from an analysis of dynamics in VI, we can show that although SIDS are generally the most vulnerable countries in the world, there are countries that are more vulnerable than others. Their vulnerability is partly driven by several common characteristics, such as isolation and extreme exposure to the effects of climate change. However, the degree of overall exposure changes with regard to analyzed dimensions of vulnerability. Our results are useful to give indications to policy-makers for

interventions to promote the adaptation strategies suggesting the more relevant dimensions of each country's vulnerability on which it needs to act and to allocate adaptation resources.

The priority given to economic growth usually means that adaptation policies are rarely implemented with determination. Local government decisions can be driven by short-term priorities for economic growth and competitiveness, while facing climate change requires a longer-term perspective. However, the international cooperation financial resources can help to combat the vulnerability of Small Island Developing States and help to promote adaptation strategies by supporting the construction of an economically and environmentally sustainable framework, from the realization of off-grid electricity to improving relationships between political actors, which have become essential to promote adaptation policies. The international cooperation has the potential to help poor countries in supporting the adaptation policies against the risks caused by climate change (Nakhooda et al., 2014) by creating new incentives for green development. The indications provided in this paper can guide policymakers to better allocate their resources, but the effectiveness of this strategy must be monitored and eventually adjusted if the adopted instrument overshoots its goal.

A point of interest is the effectiveness of the international cooperation funds received by SIDS in promoting policies to improve the adaptation. This will be the aim of further research.

Appendix A

Country	ISO	2005	2009	2010	2011	2012	2013	2014
Aruba	ABW	0.289	0.220	0.219	0.220	0.212	0.200	0.202
Antigua and Barbuda	ATG	0.306	0.288	0.267	0.262	0.258	0.272	0.281
Bahrain	BHR	0.396	0.340	0.337	0.299	0.283	0.281	0.276
Bahamas, The	BHS	0.347	0.330	0.315	0.303	0.296	0.309	0.317
Belize	BLZ	0.367	0.366	0.380	0.370	0.336	0.322	0.335
Barbados	BRB	0.135	0.109	0.112	0.144	0.135	0.113	0.132
Comoros	COM	0.401	0.403	0.415	0.434	0.382	0.402	0.404
Cabo Verde	CPV	0.434	0.405	0.388	0.397	0.374	0.386	0.400
Cuba	CUB	0.309	0.287	0.297	0.292	0.277	0.274	0.286
Dominica	DMA	0.314	0.302	0.286	0.296	0.292	0.290	0.302
Dominican Republic	DOM	0.357	0.346	0.364	0.355	0.307	0.308	0.332
Fiji	FJI	0.407	0.383	0.373	0.382	0.358	0.358	0.380
Guinea-Bissau	GNB	0.504	0.509	0.493	0.502	0.476	0.481	0.497
Grenada	GRD	0.253	0.242	0.254	0.265	0.255	0.250	0.259
Guyana	GUY	0.368	0.348	0.341	0.348	0.339	0.326	0.328
Haiti	HTI	0.521	0.469	0.505	0.523	0.477	0.482	0.515
Jamaica	JAM	0.364	0.312	0.319	0.329	0.313	0.313	0.323
Kiribati	KIR	0.599	0.595	0.585	0.606	0.582	0.600	0.618
St. Kitts and Nevis	KNA	0.256	0.243	0.232	0.256	0.252	0.261	0.294
St. Lucia	LCA	0.290	0.264	0.248	0.278	0.261	0.259	0.271
Maldives	MDV	0.469	0.393	0.410	0.431	0.426	0.437	0.443
Mauritius	MUS	0.254	0.237	0.220	0.223	0.229	0.217	0.235
Papua New Guinea	PNG	0.545	0.529	0.515	0.518	0.522	0.529	0.531
Singapore	SGP	0.091	0.089	0.081	0.133	0.167	0.141	0.142
Solomon Islands	SLB	0.542	0.522	0.518	0.540	0.513	0.519	0.545
Sao Tome and Principe	STP	0.474	0.466	0.446	0.452	0.462	0.471	0.492
Suriname	SUR	0.357	0.327	0.329	0.329	0.318	0.322	0.326
Seychelles	SYC	0.335	0.337	0.356	0.275	0.366	0.394	0.398
Tonga	TON	0.369	0.369	0.365	0.361	0.336	0.324	0.341
Trinidad and Tobago	TTO	0.207	0.207	0.204	0.209	0.213	0.211	0.220
St. Vincent and the Grenadines	VCT	0.320	0.301	0.301	0.320	0.297	0.288	0.310
Vanuatu	VUT	0.538	0.490	0.472	0.484	0.452	0.466	0.476
Samoa	WSM	0.458	0.448	0.436	0.428	0.411	0.407	0.417

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